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Research Article

Investigation of Capillary Heat Exchanger Heat Transfer for Heat Pumps in Coastal Regions at Various Times of Daily Operation

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Abstract:

The optimized design of capillary heat exchangers and their creative engineering uses in buildings are examined in this study. In order to make it easier to implement renewable energy in buildings, this study aims to extract energy using a capillary heat exchanger as the heat pump's front-end device in coastal areas. First, the primary determinants of capillary heat transfer efficiency in coastal regions were investigated in this work. Second, numerical calculations were performed on the capillary heat transfer in the situation of irregular operation patterns in the summer and winter, respectively, in order to increase the capillary heat exchanger's heat transfer efficiency. The results showed that the capillary input and output temperatures differed by 2.1 °C over the eight hours of daily operation of the capillary heat exchanger. Furthermore, the rate of heat transport was 87.1 W/m2. The temperature differential between the capillary inlet and outflow was 2.6 °C during the summer. Furthermore, 107.8 W/m2 was the heat transmission rate. This article supports the use of cutting-edge and environmentally friendly technology in coastal development, such as heat pumps and capillary heat exchangers, which can be applied to the extraction of renewable energy and the usage of buildings in close proximity to the coast.

Keywords: Heat pump, Diary operation, Capillary heat exchanger, Coastland.

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INTRODUCTION

Previous research has focused on the development pof renewable energy sources [1] [2]. For a long time, research on the heat transfer mechanism of ground source heat pump buried pipe heat exchangers has mainly beenapplied to deterministic heat transfer theory. Due to the fact that the working environment near the coast involves heat exchange in

geotechnical media, there are still few reports on the mechanism of capillary heat transfer in coastal areas, especially research on intermittent heat transfer phenomena. In practical engineering, the factors that affect the normal operation of capillary heat exchanger systems are extremely complex and diverse, and many factors themselves have significant uncertainties, or existing theories and technologies cannot obtain complete data. The deterministic stock theory and methods currently used cannot explain the heat transfer phenomenon of intermittent operation of ground source heat pumps well. Due to the lack of appropriate theoretical guidance, there are often significant deviations in the design and construction of capillary heat exchangers for ground source heat pumps, leading to problems such as excessive initial investment or insufficient heat exchange function in the project.

The application of heat pump technology to increase building energy efficiency is highly recognised. Using the exergy cost approach, Farshi et al. [3] assessed the heat pump's heat economy. A field measurement and study of the real seawater source heat pump regional heating system's energy efficiency was conducted by Shu et al. [4]. The seawater source heat pump unit's heating performance coefficient (COP) was 2.43. A coupled heat exchange system consisting of an electric heat pump, a low temperature heat grid, and a ground source heat pump was examined by Marrasso et al. [5]. Conventional ground source heat pump systems use underground heat exchange tubes in a variety of configurations [6]. A few academics have completed certain research projects [7–15]. China's capillary tube research currently focuses primarily on radiant heating and cooling at the air conditioning system's conclusion. The front-end heat exchanger system is using capillary tubes, and theoretical study is maturing. The use of capillaries as front-end heat exchangers in seawater source heat pumps to extract energy has not been extensively studied. The way capillary heat exchangers are used in front-end and back-end systems differs fundamentally. End radiation heat exchangers and capillary front-end heat exchangers work quite differently and exhibit different heat transfer patterns. It is not possible to immediately apply the theory of the capillary radiation heat transfer system to the capillaries' front-end heat transfer system.

Previous scholars have used capillary heat exchangers as the end-radiant system for air conditioning. Lazarus [16] suggested placing a capillary heat exchanger underground in a greenhouse to keep the indoor temperature at night at 12 ℃. Attar et al [17] used numerical simulation methods to study the effects of length and water flow rate of capillary heat exchangers on heat transfer efficiency. And energy consumption was reduced by 25% under heating conditions in December and 51.08% under cooling conditions in April. Water was used as the cold source. Capillary heat exchangers were used to extract energy at a depth of 30 m underground. It was concluded that the thermal efficiency of the Salamabo Museum and Aquarium in Tunisia was approximately 80%. Hazami et al [18] [19] described a device for solar energy storage combined with capillary tubes.

This paper considers coupling seawater and ground source heat pumps together, fully utilizing the thermal energy of seawater and seabed sand, and proposes a new method of burying capillaries in shallow coastal areas as the front heat exchanger of seawater source heat pump systems to extract heat and cold. This method will not cause seawater corrosion to the equipment and pipelines. It does not require additional filtering and other auxiliary equipment. It is not affected by geology, and it does not occupy public areas. It can better improve the energy extraction ability of capillary heat exchangers. The soil temperature in the seabed sand layer is higher in winter and lower in summer, which is more conducive to achieving energy-saving operation of heat pump units. This is more conducive to the energy-saving operation of the heat pump unit and may bring the underwater buried pipes closer to the coast.

This article placed a capillary heat exchanger as an energy extraction device in the soil beneath seawater in coastal areas. It used capillaries as a device for extracting underground energy. During the process of energy extraction, the temperature of seawater and the intermittent working time of the capillary had a significant impact on the heat transfer of the capillary. Therefore, this article focuses on four different daily working time modes and investigates the heat transfer performance of capillary heat exchangers under different daily operating times. The objectives of this study focus on three aspects, namely the temperature difference of the capillary tube inlet and outlet, the heat transfer of capillaries, and the soil temperature around the capillary tube.

METHOD

Capillary heat exchanger system

Equation 1 is used to compute thermal energy in accordance with the theory of heat transmission. It is predicated on how a capillary heat exchanger's heat transfer medium exchanges heat.

$$Q = mc_p \Delta t = kAT_m$$

Where W. m is the total number of parallel capillaries needed and Q is the fundamental heat rate. W/ (m2▪ ℃) is the heat transfer coefficient, or cp. It is the fluid's temperature differential, expressed in degrees Celsius, between a capillary tube's input and output. The coefficient of heat transfer is K. A is the temperature difference's cross-sectional area, expressed in °C.

The heat exchanger is made up of capillary tubes with a 4.3 mm outer diameter, 2.8 mm inner diameter, and 0.75 mm wall thickness. As seen in Figure 1, the plastic capillary tubes are spaced 20 mm apart. Ethylene glycol serves as the capillary's medium [9].

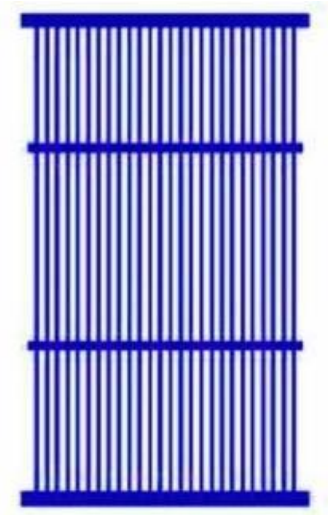

Figure 1. Capillary network with a spacing of 20mm.

Capillary application of numerical simulation

The capillary tube that makes up the heat exchanger has an exterior diameter of 4.3 mm, an inner diameter of 2.8 mm, and a wall thickness of 0.75 mm. As seen in Figure 1, there is a 20 mm gap between each plastic capillary tube. Ethylene glycol serves as the medium within the capillary [9].

Table 1. Capillary Heat Exchanger System Parameters.

Parameter	Glycol	Capillar	Seawater	Soil
Coefficient of thermal conductivity （W/(m▪K)）	0.53	0.24	0.56	1.6
The density（kg/m^3）	1015	900	1025	1600
The specific heat at constant pressure （J/(kg▪K)）	3980	2000	4217	2530
Pr	0.53			

Capillary heat exchangers gather energy from the surrounding sand and concentrate it around the capillary. The capillary's ability to transfer heat will resume if the heat exchanger system is turned off. Studying the intermittent operation of capillary heat exchangers is therefore essential. Capillary heat exchangers with sporadic daytime operation. When the capillary stops working, it's assumed that heat transfer is still occurring and that the soil temperature surrounding the buried pipe is either higher in the summer or lower in the winter than the capillary wall temperature. The state at the start of capillary operation will not be entirely restored to the capillary performance. Additionally, heat is building up. A short capillary flowing time per day indicates good soil thermal recovery.

The length of the capillary was 3.0 m. The distance between the capillary supports was 160 m, and the spacing between the capillaries was 20 mm. Five capillary grids were shallowly buried in soil 1.0 m above ground level. The daily working time of capillaries is less than 24 hours. The daytime intermittent operation of capillary tubes refers to the operation within 24 hours per day. This article focuses on analyzing the daytime intermittent operation of capillary heat exchangers. A model was established. And then it was simulated by using CFD. The capillary was run for one week of operation for 8, 10, 12 and 14 hours per day. It was simulated to calculate the operating conditions in winter and summer. It was prepared as a UDF file and set up in FLUENT software.

RESULTS AND DISCUSSIONS

There are some differences in the load changes of different buildings. According to the different functions of buildings, such as libraries, office buildings, shopping malls, hotels, etc., the daily operating hours of typical buildings vary. For office buildings, including office buildings, equipment operates during the day and shuts down at night. For shopping malls, the capillary heat exchanger is in operation from 10: 00 am to 22: 00 pm. For hotels, due to the fact that the daily equipment is mostly in operation, the underground capillary heat exchanger has been in continuous operation. This determines the intermittent operation mode of the capillary based on analysis. Capillary tubes run for 14 hours a day in the office building. Capillary tubes run for 12 hours a day in shopping malls. The capillary tube runs for 8 hours daily in the library. Capillary tubes run continuously daily in hotels. Due to the different functions of buildings, the daily running time of capillaries varies.

Temperature difference between capillary inlet and outlet

The capillary flow rate was 0.1 m/s. According to engineering applications, the length of each capillary was selected as 3m. It is recommended that buildings use closed-loop capillary heat transfer systems.

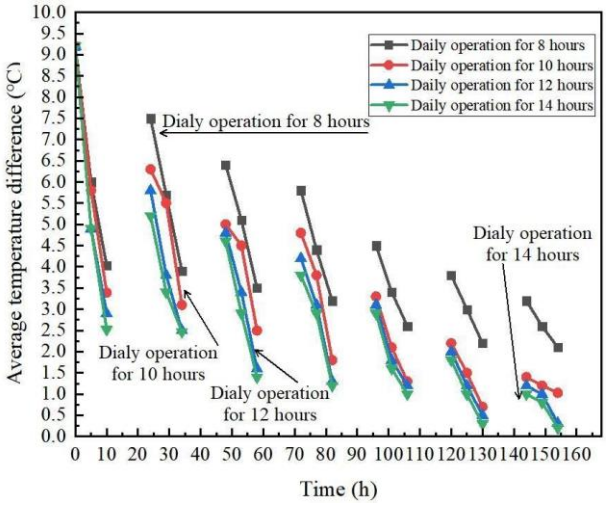
Daily operation for 8 hours
Daily operation for 10 hours
Daily operation for 12 hours
Daily operation for 14 hours
Dialy operation for 8 hours
Dialy operation for 10 hours
Dialy operation for 12 hours
Dialy operation for 14 hours
Average temperature difference (°C)
Time (h)

Figure 2. Temperature difference between capillary inlet and outlet in winter

As shown in Figure 2, the temperature difference of the capillary inlet and outlet in winter was 2.1 ℃, 1.03 ℃, 0.31 ℃, and 0.2 ℃ when the capillary was operated for 8, 10, 12, and 14 hours per day, respectively. The reason is that the operating time of these four modes gradually increases, and the time for soil temperature recovery gradually decreases, resulting in a gradual decrease for the temperature difference of the capillary tube.

The capillary heat exchanger was run for 14, 12, 10, and 8 hours a day, as depicted in Figure 3. In July, the capillary input and outflow had temperature differences of 1 °C, 1.7 °C, 2.1 °C, and 2.6 °C, respectively. The four modes' progressively shorter operation times and longer soil recovery periods are the cause of this.

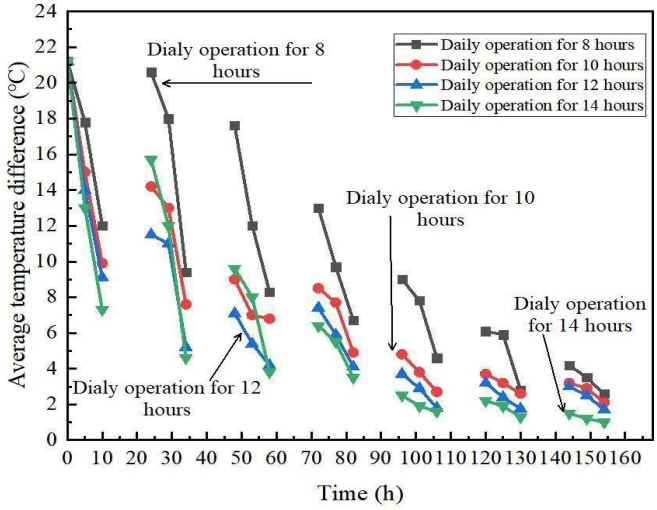
Daily operation for 8 hours
Daily operation for 10 hours
Daily operation for 12 hours
Daily operation for 14 hours
Dialy operation for 8 hours
Dialy operation for 10 hours
Dialy operation for 12 hours
Dialy operation for 14 hours
Average temperature difference (°C)
Time (h)

Figure 3. Temperature difference between capillary inlet and outlet in summer

Heat transfer per unit area for capillary heat exchange in the coastal area

The winter heat transfer rate per unit area was 87.1 W/m^2, 42.7 W/m^2, 12.9 W/m^2, and 8.3 W/m^2, as illustrated in Figure 4, following 168 hours of operation with the capillary heat exchanger running for 8, 10, 12, and 14 hours a day. This is because the recovery period lengthens and the working time of these four modes gradually increases, leading to a gradual decline in the heat transfer rate per unit area during the winter.

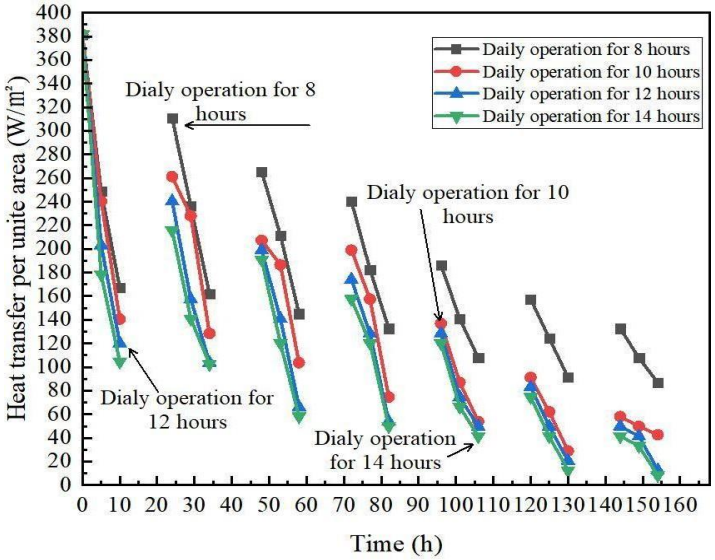
Heat transfer per unite area (W/m²)
Time (h)
Daily operation for 8 hours
Daily operation for 10 hours
Daily operation for 12 hours
Daily operation for 14 hours
Dialy operation for 8 hours
Dialy operation for 10 hours
Dialy operation for 12 hours
Dialy operation for 14 hours

Figure 4. Heat transfer per unit area for capillary heat exchange in winter.

As shown in Figure 5, after running for 168 hours, when the capillary heat exchanger run for 8, 10, 12, and 14 hours per day, the heat transfer rates per unit area capacity in summer were 107.8 W/m^2 , 87.1 W/m^2 , 70.5 W/m^2 and 41.5 W/m^2 , respectively. The reason is that the running time of the four models gradually increases, and the duration of the soil temperature recovery period decreases.

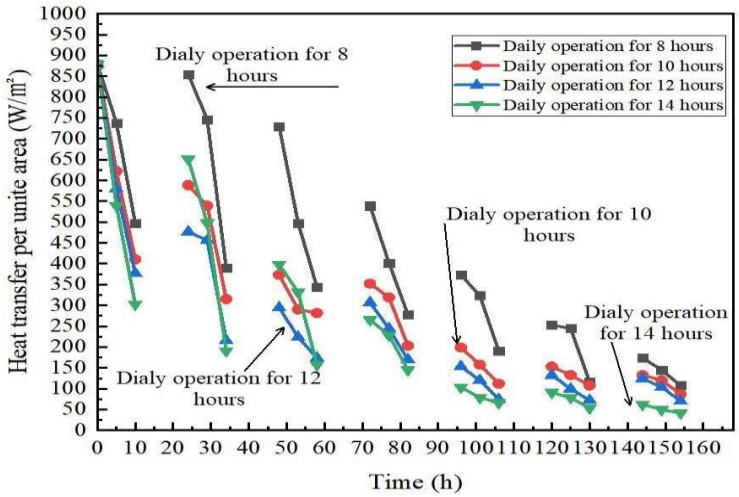
Heat transfer per unite area (W/m²)
Time (h)
Daily operation for 8 hours
Daily operation for 10 hours
Daily operation for 12 hours
Daily operation for 14 hours
Dialy operation for 8 hours
Dialy operation for 10 hours
Dialy operation for 12 hours
Dialy operation for 14 hours

Figure 5. Heat transfer per unit area for capillary heat exchange in summer.

Soil temperature around the buried capillary area

Figure 6 illustrates how the capillary heat exchange caused the winter soil temperature to rotate. During the winter, the soil temperatures surrounding the capillary were 1.9 °C, 0.83 °C, 0.6 °C, and 0.4 °C, respectively. These values corresponded to the four operation modes of 8, 10, 12, and 14 hours per day. The four modes' progressively longer working times and the capillary pipe's increased absorption of heat from the surrounding soil are the causes. The outcome is a progressive drop in soil temperature near the buried pipe region.

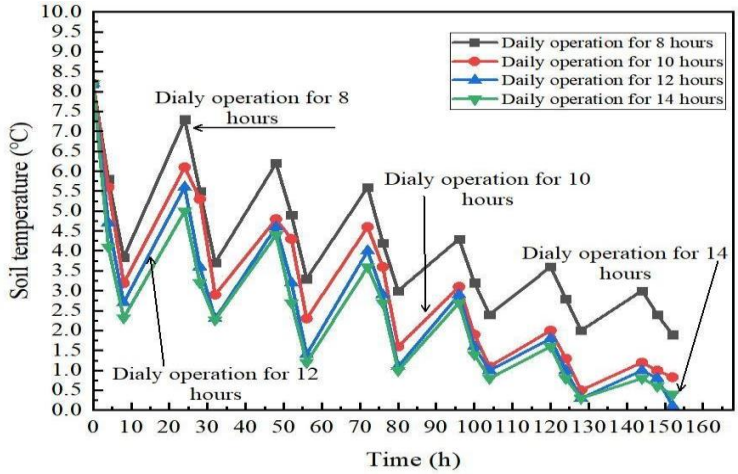
Daily operation for 8 hours
Daily operation for 10 hours
Daily operation for 12 hours
Daily operation for 14 hours
Dialy operation for 8 hours
Dialy operation for 10 hours
Dialy operation for 14 hours
Dialy operation for 12 hours
Soil temperature (°C)
Time (h)

Figure 6. Soil temperature around capillary heat exchange in winter.

As shown in Figure 7, it is the temperature around the capillary heat transfer of soil in summer. The soil temperature around the capillary corresponding to the four operating modes of 8, 10, 12, and 14 hours per day was 35.2 ℃, 35.7 ℃, 36.1 ℃, and 36.8 ℃ , respectively. The reason is that the operating time of these four modes gradually increases, and the capillary releases more heat into the surrounding soil. Therefore, the soil temperature around the buried pipeline area gradually increases.

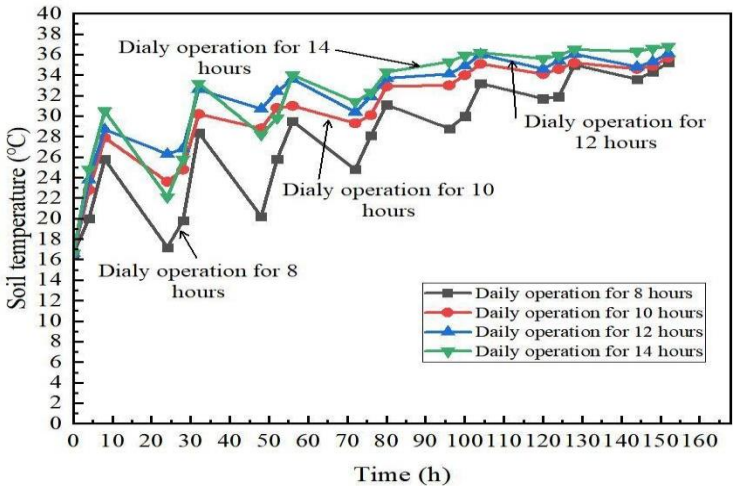
Dialy operation for 14 hours
Dialy operation for 12 hours
Dialy operation for 10 hours
Dialy operation for 8 hours
Daily operation for 8 hours
Daily operation for 10 hours
Daily operation for 12 hours
Daily operation for 14 hours
Soil temperature (°C)
Time (h)

Figure 7. Soil temperature around capillary heat exchange in summer.

In the future, further research will be conducted in this field, such as tidal induced water level changes, durability, algae growth, and economic analysis, to increase practical value to users.

CONCLUSIONS

In order to supply buildings with the necessary sources of heating and cooling, a novel capillary heat exchanger is described in this work as an energy extraction mechanism. The capillary tubes in the vicinity of the coast get energy from the earth. Depending on the kind of building, the heat transfer from the capillary tubes is computed using various daily working intervals in the summer and winter. The following are the primary conclusions of this paper:

The temperature differential between the capillary heat exchanger's input and exit may be raised if its daily operating schedule is properly planned. The intake and outlet temperature differential of the capillary heat exchanger in winter are 2.1 °C, 1.03 °C, 0.31 °C, and 0.2 °C,

respectively, when the capillary heat exchanger operates for 14 hours, 12 hours, 10 hours, and 8 hours each day. The temperature difference at the capillary input and outlet in the summer is 1 °C, 1.7 °C, 2.1 °C, and 2.6 °C, respectively, while the capillary heat exchanger operates for 14 hours, 12 hours, 10 hours, and 8 hours each day.

The capillary's daily running hours are logically scheduled to increase the capillary heat exchanger's unit seat area's heat transfer efficiency. The winter seawater temperature of the capillaries installed in coastal areas is 3.7 °C. The heat transfer rates per unit area capacity after 168 hours of operation were 87.1 W/m^2, 42.7 W/m^2, 12.9 W/m^2, and 8.3 W/m^2, in that order. Seawater in the summertime was 24.6 °C, and the capillary's installed coastal areas had heat transfer rates per unit area capacity of 107.8 W/m^2, 87.1 W/m^2, 70.5 W/m^2, and 41.5 W/m^2.

The recovery of soil temperature around the capillary during the interval is related to the duration of the interval. The longer the interval, the better the soil temperature recovery.

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